A low-noise amplifier for 70 cm

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I needed a good low noise amplifier for some weak signal experimentation. After having a look around in the various places that sell them, I concluded that it is worth trying to design and build my own version of it. If nothing else, it would be an excellent learning opportunity, as I had never designed a high performance low noise amplifier before this exercise.

Luckily, the main component – the low noise High Electron Mobility Transistor (HEMT) – is being sold in small quantities by Mini-Kits [1]. The transistor, the ATF-54143 is made by Avago [2] (formerly Agilent) and has exceptional parameters on the 70 cm band.

The noise figure of this device is less than 0.2dB, which allows us to build an EME-class low noise amplifier, as long as the input matching circuit is done correctly. The HEMT is also very linear having a 3rd order intercept of +30 dBm, so it can cope well with out of band interference. The transistor is an enhancement mode HEMT, so it does not require negative gate bias supply. One other advantage of this transistor is that the optimum input impedance for minimum noise figure is close to 50 ohm, at our frequency of interest. Thus the input matching circuit can be simpler and less lossy, further improving the noise figure.

A disadvantage of the ATF-54143 HEMT is that the amplifier could be unstable in the GHz region, unless the output match circuit is designed carefully.

The ATF-54143 HEMT has been used by other builders of 70 cm preamplifiers. One good and stable design is by YU1AW [3]. I do recommend this design, if you have access to high quality trimmer capacitors and do not mind building the input resonator from a copper strip. Since I did not have the high quality trimmers and also having decided that I could live without the input selectivity, I simplified the YU1AW design and changed the input circuit. I also tweaked the output circuit a little to improve the matching. The result is a preamp on a single small printed circuit board, with no unusual or hard-to-get components, while the noise figure is still very good.

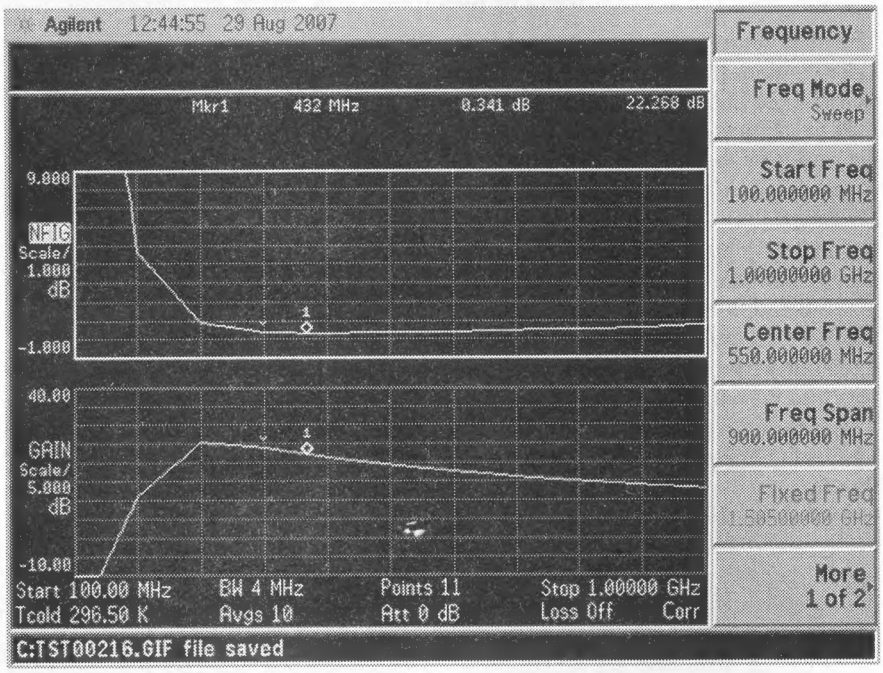

Photo 1: Measurement results showing gain and noise figure at 432 MHz.

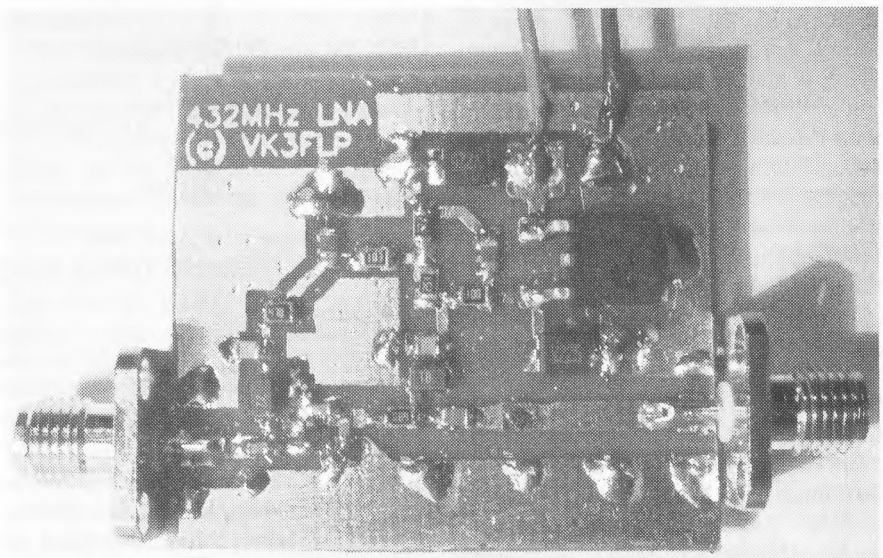

Photo 2: The completed unit.

My LNA design does not include any form of transmit-receive switching or protection, as this would depend very much on the individual application. A T/R switch design should take into account the fact that the transistor can tolerate up to about 50 mW input power according to [2], and I recommend a further 10 dB headroom.

Circuit description

Referring to the schematic diagram (Figure 3), L1 and C1 form the input matching circuit. These two components transform the input impedance of 50 ohm close to 70+j40 ohm, which is required to achieve the optimum noise figure.

Something to note is the influence of the Q factor of L1 on the total noise figure. The parasitic resistance of this inductor affects the noise figure noticeably. In this case, I have chosen an ordinary moulded SMD inductor, with a quite low Q of about 40, resulting in a measured total amplifier noise figure of 0.34 dB. Based on some quick simulation I have done, it should be possible to reduce the noise figure close to 0.2 dB, if one used a better inductor with a Q in the still achievable range of 70-100. Perhaps someone might try a hand-wound inductor, using a silver-plated wire…

The capacitor C2 provides RF ground connection for the input matching inductor and decouples the bias circuit. The bias circuit includes resistors R1, R2, R3, R4, R6 and capacitors C3 and C6. The gate bias is a positive voltage, adjusted with R3 so that the current through the HEMT is about 40 mA, and the drain voltage is about 3.3 V.

The output circuit, consisting of C4, C5, R5, L2 and C7 serves two

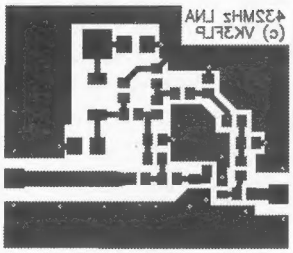

Figure 1: Image of pcb artwork.

purposes. Firstly, it ensures stability of the amplifier across the full frequency range, especially above 1 GHz. Secondly, it provides a good impedance match to a 50 ohm output at 432 MHz.

IC1 is a standard 5 V regulator. The printed circuit board has a separate connection pad for the positive power supply, but if desired, the power supply could be provided from the output coax connection. In such case, an RF choke could be soldered from the RF output line to the power input pad.

All the components are surface mount. Most of the passive components are the 0805 SMD footprint, which is still large enough to solder easily by hand (with tweezers) but small enough that the circuit performance on 432 MHz is not affected too much by the parasitic parameters. It is also possible to use 0603 size components with no adverse effect.

Assembling the amplifier

I have manufactured the printed circuit board at home using a laser printer and the iron-on transfers, sold by Jaycar. If you use a laser printer, you will need an exact 1:1 mirrored image of the board pattern, to print onto the transfer sheet.

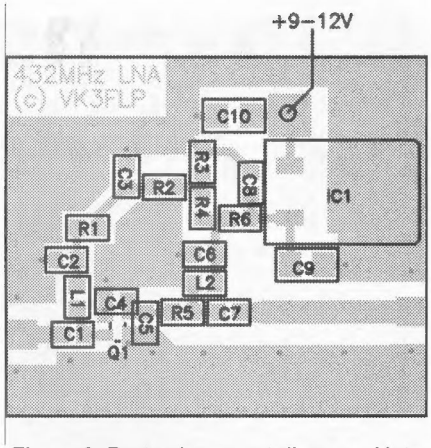

Figure 2: Parts placement diagram. Note that the grey dots represent through board vias connected to the ground plane side of the pcb (see text).

I can provide a PDF file by email. The circuit board design has been optimised for 1.2 mm double sided FR4 laminate. The bottom side of the PCB is not etched and serves as the ground plane. The top side is shown on Figure 1 and component placement is on Figure 2. The printed circuit board measures 1.46 x 1.24 inches (37.08 x 31.5 mm).

There is a number of 'via' holes which connect some pads to the ground plane. These are drilled with a 0.8 mm drill and a wire pushed through and soldered on both sides.

After preparing the PCB, all components except R3 can be soldered in. In my experience, the surface mount components can be easier to work with than through-hole and the whole preamplifier could be put together in an hour. One just needs a steady hand and good eyesight, or a magnifying glass. The Q1 is sensitive to static electricity, so I recommend the usual 'ESD' precautions.

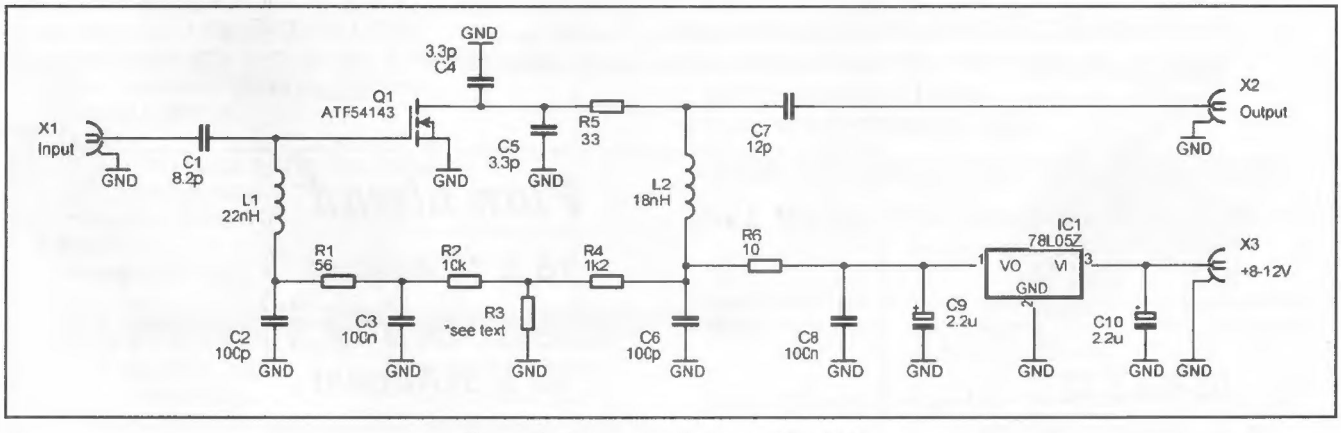

Figure 3: Schematic diagram of the LNA.

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After thoroughly checking the board, the next step is to solder a 2 k trim pot in place of R3, and turning it to the position of minimum resistance (short). Next, the power supply can be connected and turned on. The output of IC1 should be checked, and the voltage should be 5 V. Next the voltage on the drain of Q1 should be measured. It should be 5 V at this stage, as no current flows through Q1. Next, the 2 k trim pot should be carefully turned, to increase the resistance, until the Q1 drain voltage drops to 3.3 V. Turn off the power supply, unsolder the trim pot, being careful not to move it. Then measure the resistance. Select a SMD 0805 resistor (or parallel combination of resistors) with the same resistance, and solder them in place of R3. In my case, it was 200 ohm, so I chose 220 ohm in parallel with 2.2 kohm. I decided to use a fixed R3 resistor in this way, rather than a permanently soldered trimmer to ensure mechanical stability and reliability.

Results

Luckily, I have an occasional access to an Agilent N8973A noise figure analyser, so that I had a chance to check how the real circuit performs. The prototype LNA measured on this instrument showed 0.34 dB noise figure and 22 dB gain on 432 MHz. The noise figure measurement at such low values has some uncertainty, and more on this can be read on the N8973A web page [4]. The measured noise figure and gain over the frequency range 100 MHz – 1 GHz can be seen on Photo 1.

Naturally, the preamplifier should be mounted as close to the antenna as possible, to take advantage of its performance, but that would be a subject for another article. If anyone decides to build this preamplifier, I would be very much interested in the results achieved.

Component List

Q1 ATF-54143 pHEMT, Avago, available in Australia from Mini-Kits

IC1 SMD Voltage Regulator MC78M05 +5 V, Jaycar No. ZV1544

C1 8.2 pF, 0805 or 0603 SMD capacitor

C2, C6 100 pF, 0805 or 0603 SMD capacitor

C3, C8 100 nF, 0805 or 0603 SMD capacitor

C4, C5 3.3 pF, 0805 or 0603 SMD capacitor

C7 12 pF, 0805 or 0603 SMD capacitor

C9, C10 2.2 uF, tantalum capacitor, 3216 surface mount, Jaycar No RZ6544

L1 22 nH, 0805 SMD inductor

L2 18 nH, 0805 SMD inductor

R1 56 ohm, 0805 SMD resistor

R2 10 kohm, 0805 SMD resistor

R3 see text

R4 1.2 kohm, 0805 SMD resistor

R5 33 ohm, 0805 SMD resistor

R6 10 ohm, 0805 SMD resistor

X1, X2 SMA female connectors, or solder coaxial cable directly

References

[1] Mini-Kits web site http://www.minikits.com.au

[2] ATF-54143 datasheet, http://www.avagotech.com/products/product-detail.jsp?navId=H0,C1,C5230,C5088,P94057

[3] http://www.qsl.net/yu1aw/atf54143eng.htm

[4] http://www.home.agilent.com/agilent/product.jspx?cc=US&lc=eng&nid=-536902736.536880065&pageMode+OV

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